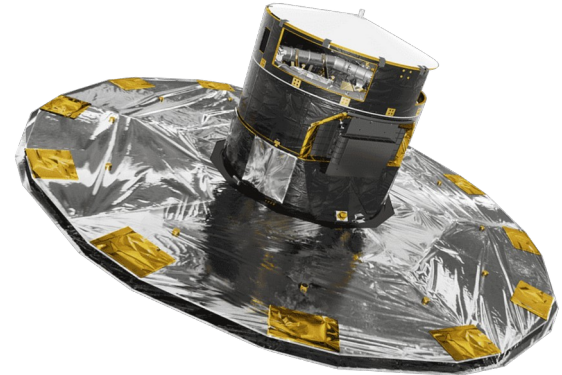
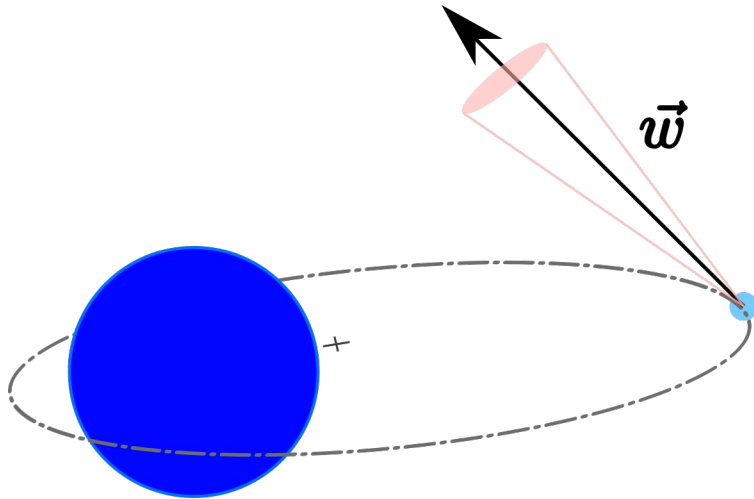
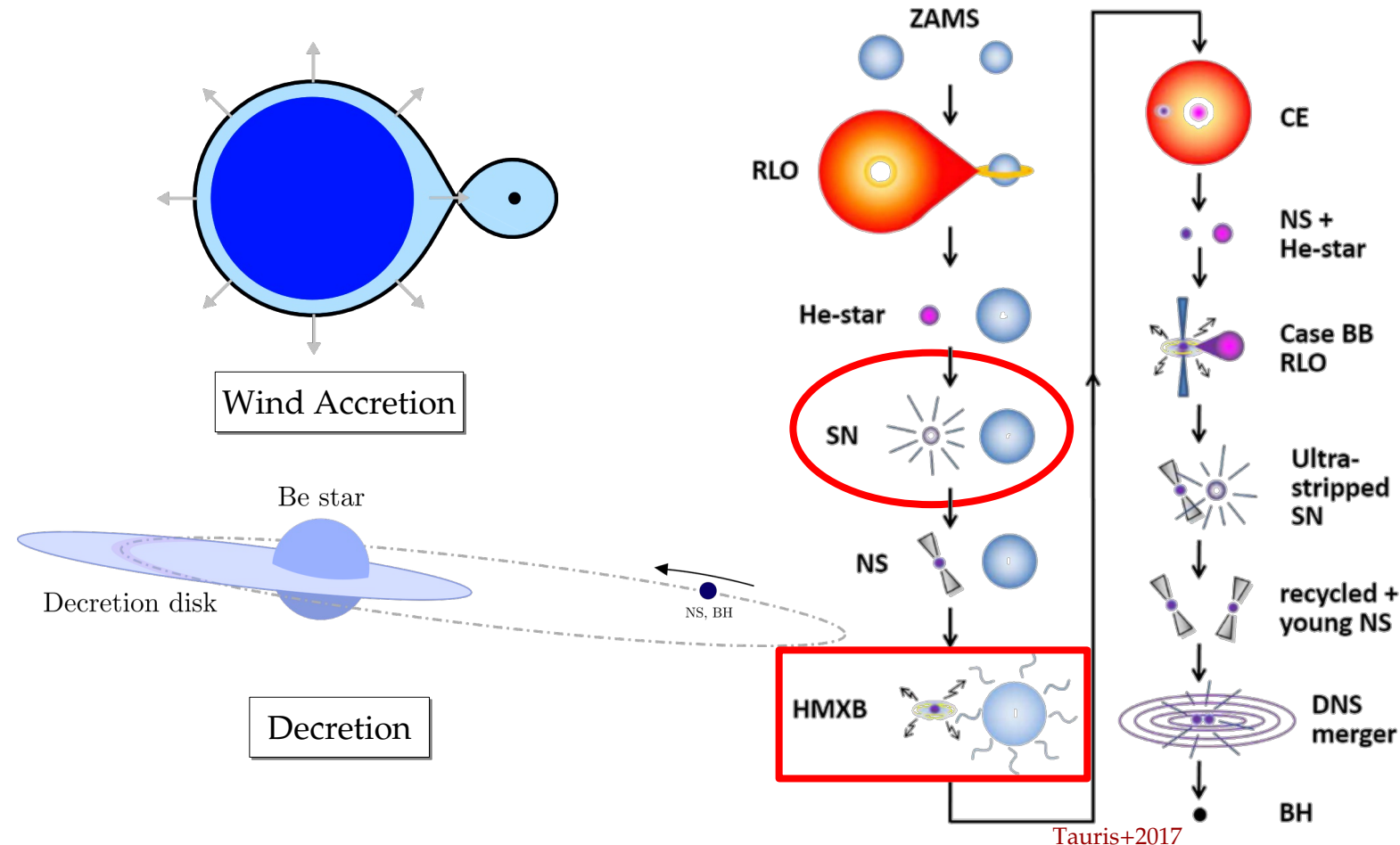


Constraints to neutron star kicks in High-Mass X-ray binaries with Gaia EDR3




F. Fortin, F. Garcia, S. Chaty, E. Chassande-Mottin & A. Simaz-Bunzel, A&A 2022a

Evolution of High-Mass X-ray binaries



Survival rate ?
Impact on orbit ?

Natal kicks – State of the art & Aims

- Analytical solution of its impact on orbital parameters in binaries (Kalogera 1996)
- Cir X-1 velocity & orbit explained by massive natal kick of ~ 500 km/s (Tauris+1999)
- Black Hole X-ray binary with high runaway velocity (Mirabel+2002)
- Isolated pulsars: preferential direction of the kick wrt spin ? (Ng & Romani 2013)
- Natal kick derived on an HMXB with the Australian LBA radio interferometer (Miller-Jones+2018)
- Radio interferometry + Gaia DR2  to derive kick on 16 BH X-ray binaries (Atri+2019)

Kicks are still misunderstood, most studies tackle a single source in the case of binaries

- Infer the NS kick magnitude in known HMXBs of our Galaxy
- Use of astrometric data from Gaia EDR3
- Characterize the NS kick distributions across HMXB subtypes

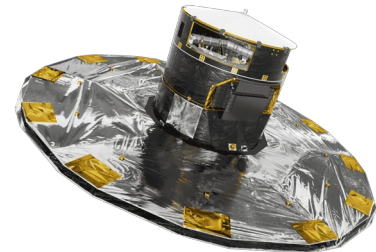
Pre-requisites

- i) build a list of HMXBs known in the Milky Way
 - cross-match between old HMXB catalogue ([Liu+2006](#)) with current INTEGRAL sources ([Bird+2016](#))
 - cross-match with Simbad (Centre de Données astronomiques de Strasbourg)
 - some candidate HMXBs in previous catalogues are now confirmed/discarded
 - retrieve exact references for spectral type, mass, period, eccentricity, radial velocity (1D)

- ii) find the Gaia counterparts of those HMXBs & retrieve position (3D) and proper motion (2D)

→ 6D data (position + proper motion + radial velocity)

Peculiar Velocity = Velocity – Galactic orbital motion



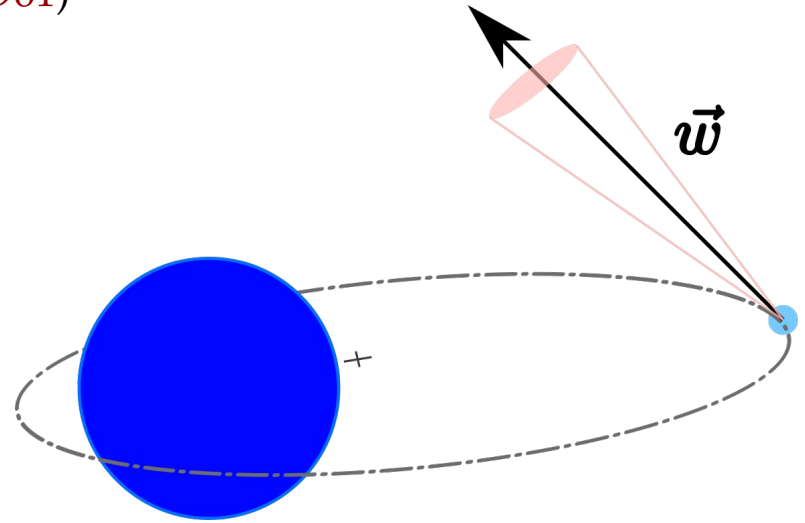
Deriving neutron star kicks

Analytical equation linking pre-SN to post-SN orbital parameters (Kalogera 1996), assuming an **isotropic probability of the kick direction**.

- Blaauw kick (spherically symmetric mass loss, Blaauw 1961)
- Asymmetric kick (random direction)

Hypotheses:

- circularized systems Dosopoulou & Kalogera 2016
- fixed NS mass @ $1.4M_{\text{Sun}}$ Kiziltan+2013
- companion is unaffected by the supernova Liu+2015

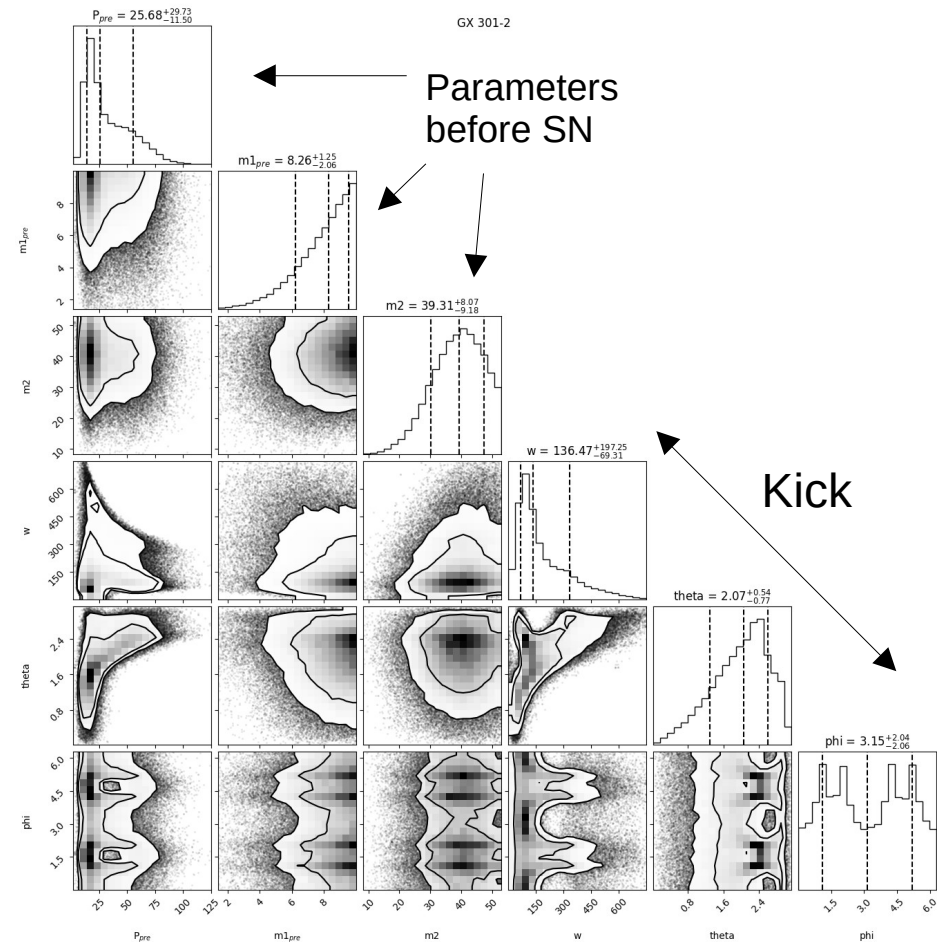


Deriving neutron star kicks

Bayesian approach:

- Priors on kick magnitude, initial P_{orb} and pre-SN mass
- Likelihoods: Gaia observables, companion mass, P_{orb} & eccentricity

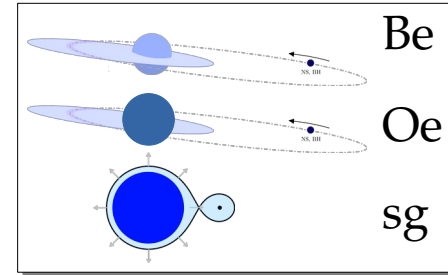
→ Explore the posterior distributions using Markov Chain Monte Carlo (MCMC)



Inferring kick distributions on HMXB subtypes

We have a posterior probability of kick velocities for each 35 HMXBs.

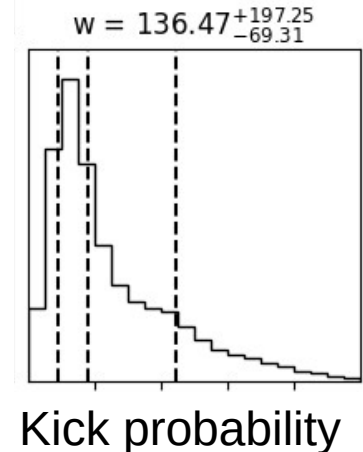
→ How can we characterize the kick distributions on each HMXB subtypes ?



To get a representative distribution, we use a bootstrap method:

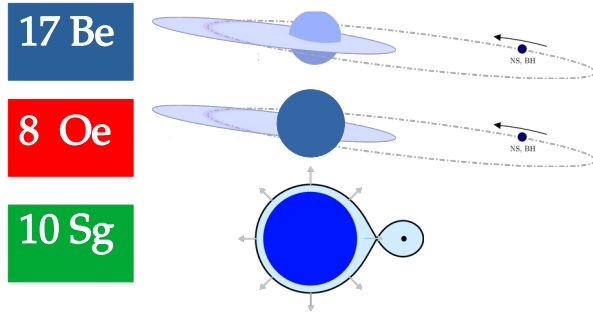
- for each HMXB, draw a random kick velocity according to its posterior probability
- 1 bootstrap iteration is a collection of those random draws, effectively one possible posterior for the whole HMXB subtype population in question
- iterate 1000 times

→ Fit each posteriors with a Gamma function, retrieve median parameters.



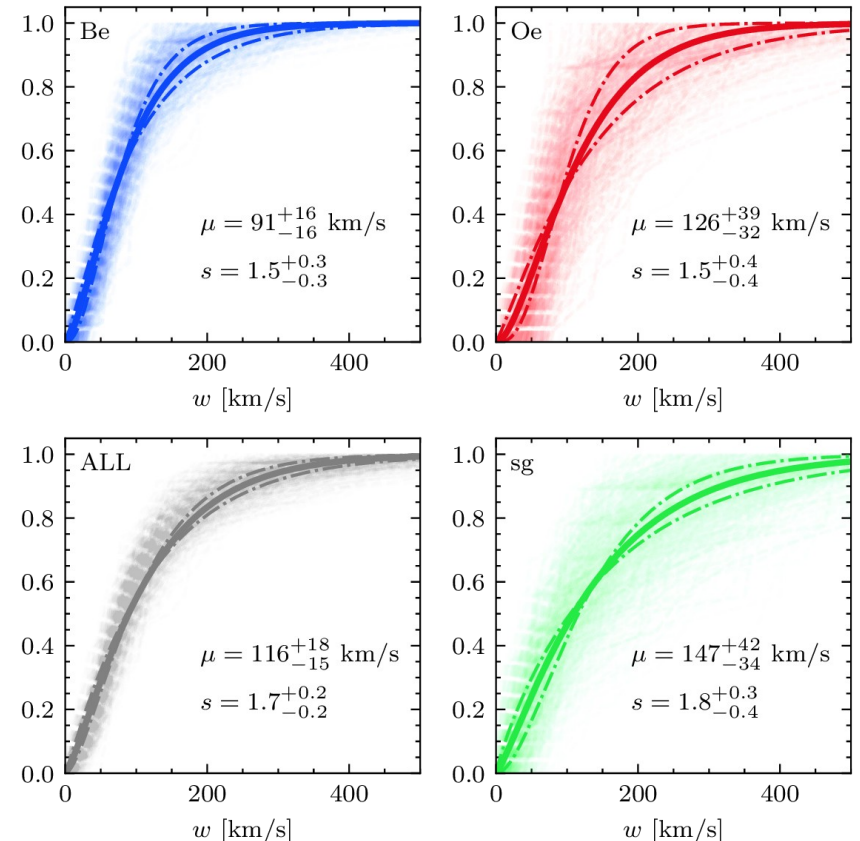
Results on kick distributions

Inferred kick magnitudes on 35 HMXB :



- Kicks are reproduced with Gamma functions
- Less low-kick contribution
- Can be confronted to population synthesis models in order to constrain the physics behind NS kicks

Cumulative distributions of kicks



Prospects: Gaia DR3 & the birthplace of HMXBs

- Upcoming release(s) of Gaia

- Gaia DR3 improvement over EDR3: addition of astrophysical parameters & some RVs
- No additional source, no improvement on astrometry
- Full release TBD, extra sources with more constrained astrometry.

- Finding the birthplace of HMXBs in the Galaxy (Fortin et al. A&A 2022b)

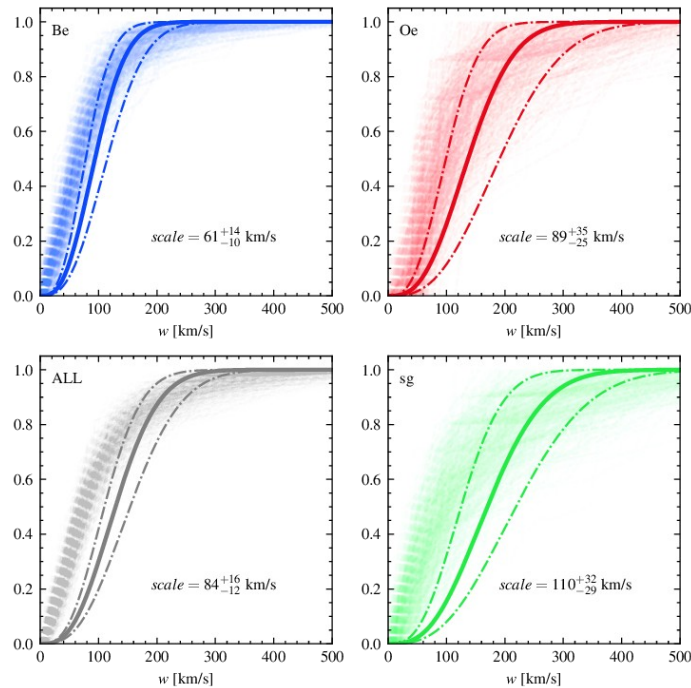
- We have the peculiar velocity of HMXBs
- If they are born within clusters, we could find them in Gaia → get their peculiar velocity
- Integrate orbits over \sim Myr to find candidate birthplaces for Galactic HMXBs.

Thank you for your attention !

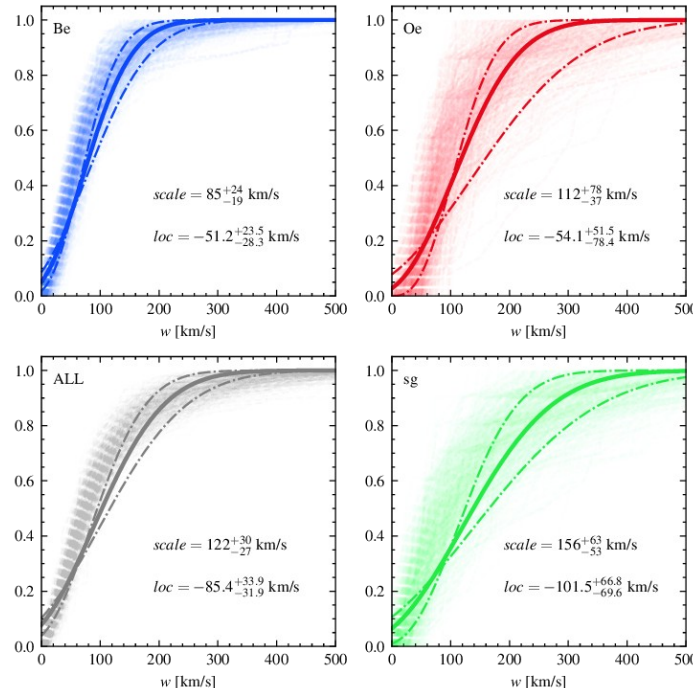


Extra: Maxwellian vs. Gamma

Maxwellian is historically used to model kicks in isolated pulsars (Hobbs+2005, Ng & Romani 2007, Noutsos+2013)



Classical Maxwellian



Shifted Maxwellian

Unbound systems ?

→ observed vs. pop synth.

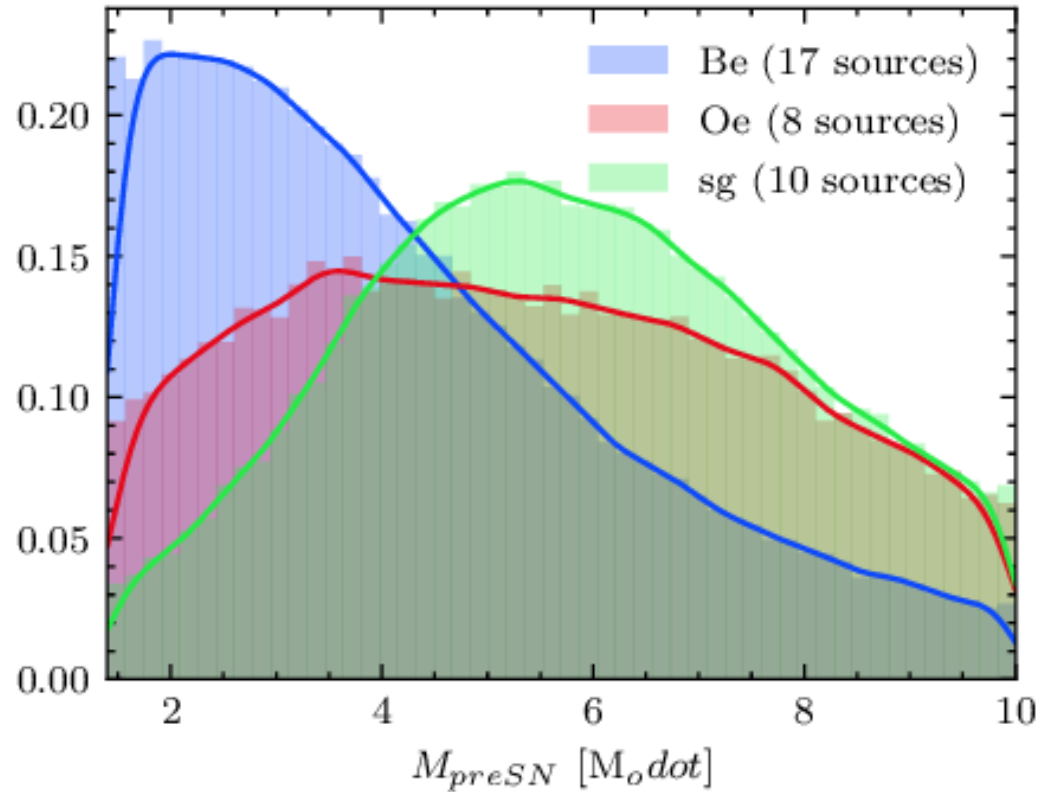
Stripped progenitors ?

→ lower pre-SN mass

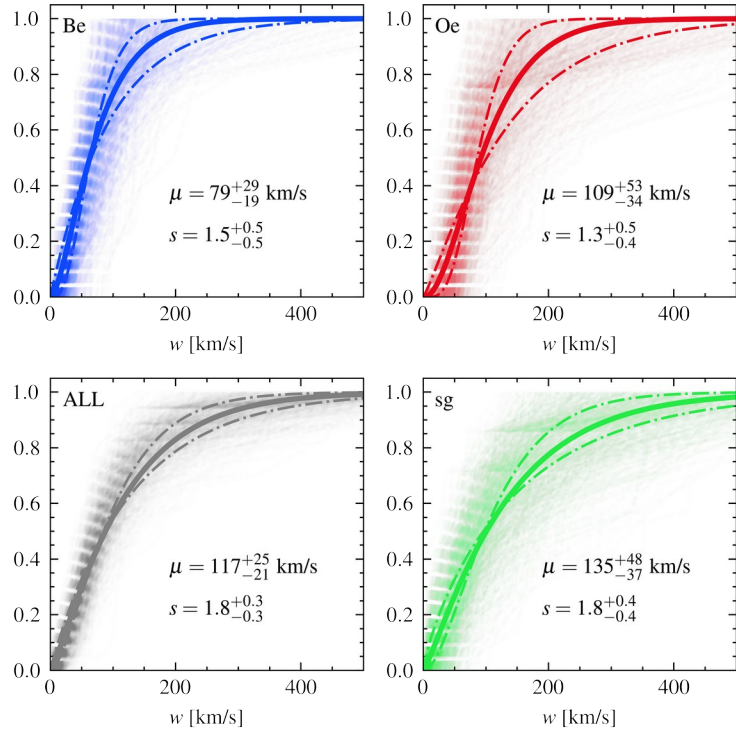
Kick isotropy ?

→ NS spin axis

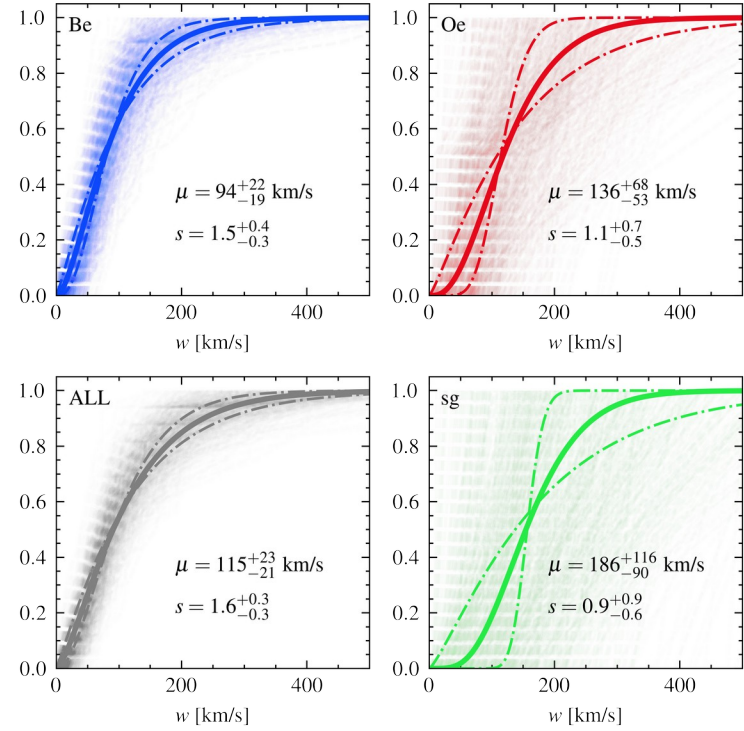
Extra: $M_{\text{pre-SN}}$ distribution



Extra: impact of missing radial velocity



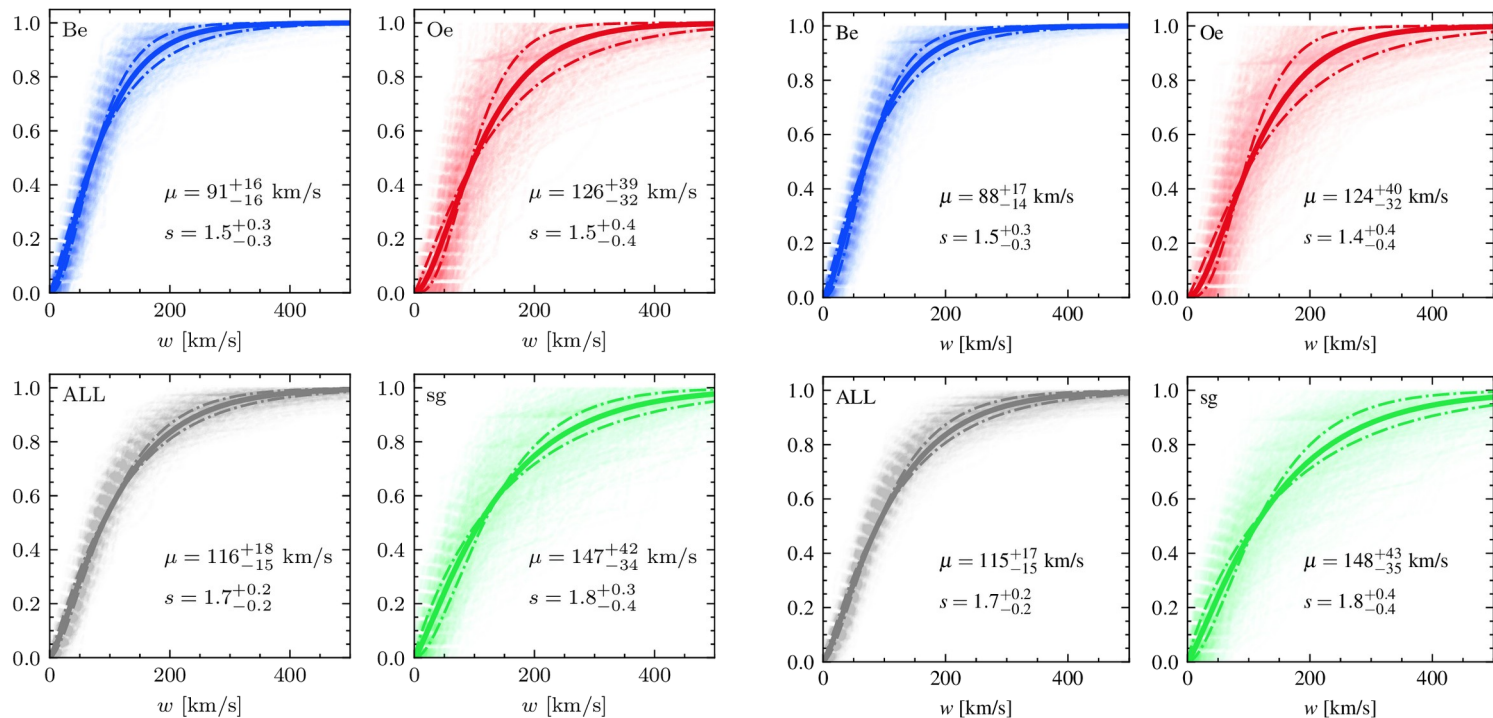
With RV only



Without RV only

Extra: impact of neutron star mass

→ Assumed constant NS mass of 1.4 Msun, what about more massive NSs ?



$M_{\text{NS}} = 1.4 M_{\text{Sun}}$

$M_{\text{NS}} = 1.8 M_{\text{Sun}}$

No notable difference
on the fitted
parameters

→ NS mass variation
are much smaller
than $M_{\text{pre-SN}}$
uncertainty

Extra: building the list of HMXBs

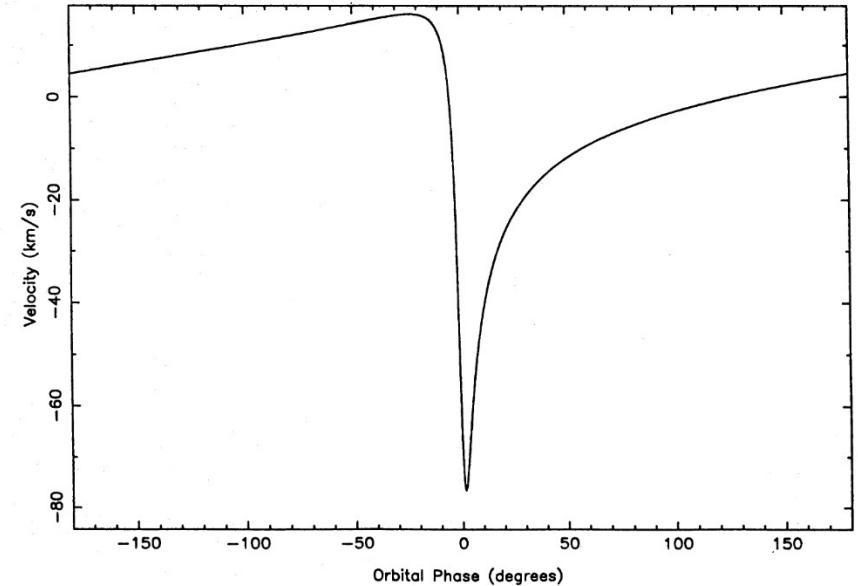
Example: PSR B1259-63

Radial velocity followup of the Oe companion star

→ Curve is presented but no value of the systemic velocity is given in the paper !

→ WebPlotDigitizer: we retrieved the data from the plot and fitted the systemic velocity

→ Do that for 130 HMXBs in the Galaxy.



Radial velocity of PSR B1259-63 (Johnston+1994)